VOLUME 81 PAPER No. 756

PROCEEDINGS

AMERICAN SOCIETY
OF
CIVIL ENGINEERS

JULY, 1955

SETTLEMENT ANALYSIS OF SAND DRAIN PROJECTS

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SOIL MECHANICS AND FOUNDATIONS DIVISION

{Discussion open until November 1, 1955}

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

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This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N. Y.

SETTLEMENT ANALYSIS OF SAND DRAIN PROJECTS

Edward A. Henderson,[1] A.M. ASCE

SYNOPSIS

Estimated time rates of embankment settlement are compared with settlements observed on two separate highway projects in New Jersey where vertical sand drains were installed. The observed settlements cover a period of about two years after placement of pavement. Subsurface conditions at each site together with laboratory soil test data are given. Methods used to estimate the time rates of settlement are outlined.

INTRODUCTION

Vertical sand drains have been used on several projects in New Jersey where roadway embankments were constructed over soft compressible soils. This paper is concerned only with comparisons of estimated and observed settlements and methods of estimating time rates of settlement where vertical sand drains were used on two specific projects. Other phases of design and construction using vertical sand drains are not covered except general descriptions of the specific projects involved.

The two projects considered were both constructed by the New Jersey Highway Department with O. J. Porter as special consultant and are:

A) N. J. Route 35, Sec. 40-A, South Approach to Manasquan River Bridge, Point Pleasant, New Jersey.
B) N. J. Route 151, Sec. 1-A, Approach to Memorial Avenue Bridge, Camden, New Jersey.

The author was associated with both projects during their entirety, but all work for this paper was done in 1954 about three years after construction. All information contained herein was taken from the records of the New Jersey Highway Department. Test data was lacking or incomplete in some respects but possibly represents an average amount that would be available to an engineer concerned with a vertical sand drain installation. No information was available on the horizontal coefficient of consolidation. In making estimates of settlements, various assumed values were used.

The purpose of this paper is to present data on completed projects and compare actual settlements and estimated settlements based on available data. The procedures used to estimate settlement are given or referenced so that the results which are the only non-factual material presented may be compared to results arrived at by other methods.

The comparisons of settlement rates are limited to one location at each project where bore holes, test data on undisturbed samples and settlement platform records coincided.

1. Soils Engr., Goodkind & O'Dea, Hamden, Conn.

Description of Projects

Route 35 (Point Pleasant) Project

The embankment at this project was constructed over a tidal mud flat adjacent to an existing causeway and formed the approaches to a high level bridge over the Manasquan River. The embankment cross-section is shown in Fig. 1. The first operation on the project was to dredge to Elevation - 10.0 and backfill with hydraulic sand. Dredging to Elevation - 10.0 was not considered necessary for the design of this project but was dictated by the requirements of a proposed adjacent project. After backfilling, a 3.5 foot thick sand blanket layer was placed and settlement platforms installed. Settlement readings began at this point. Any settlement prior to installation of the platforms was not measured. Vertical sand drains 20 inches in diameter were then installed by use of a closed end mandrel. The drains were on a square pattern and varied from 7 ft. on centers to 10 ft. on centers. At the location being considered for this paper, the spacing was 8 ft. on centers. Embankment was placed at a rate of about 2 ft. per week to overload grade. The overload was left in place about eight months, then removed, and the project paved. The elevations of the top of embankment vs. time are shown in Fig. 9.

Route 151 (Camden) Project

The embankment at this project was constructed over a flag layer that had been placed over a swamp adjacent to a tidal river. The embankment cross-section is shown in Fig. 2. As the slag layer formed a suitable working platform, the first operation was to drive 18 inch diameter vertical sand drains on a square pattern 10 ft. on centers by means of a closed end mandrel. An attempt was made to install the drains without using air pressure inside the mandrel. This was unsuccessful as the sand drain backfill material tended to stay in the mandrel due to arching. After the drains were placed, their tops were cleaned and an 18 inch thick sand blanket layer was placed. Embankment was placed at a rate of 4 ft. per week during early stages, then reduced to 2 ft. per week and again reduced to 1 ft. per week near the top of embankment. The overload was left in place about one year. Eight months elapsed after overload removal before pavement was placed. Elevations of the top of embankment vs. time are shown in Fig. 10.

Subsurface Conditions

Route 35 (Point Pleasant) Project

The compressible soils at this site consisted of a top layer of soft gray clay underlain by soft black clay. Both were of marine origin. Beneath the clays a thick sand bed existed. For computing rates of settlement, this sand was considered pervious and capable of providing free drainage at the lower horizontal clay boundary. In practice, it is doubtful if full free drainage exists.

Route 151 (Camden) Project

The compressible soil at this site was a gray marine clay overlain by a waste slag layer and underlain by sand. As at the Point Pleasant Project, the sand was considered capable of providing free drainage. As the slag was somewhat of a porous nature, it was considered capable of providing partial

drainage at the upper horizontal clay boundary. The soil profiles at both projects are shown in Fig. 3.

Soil Proper Ties

Samples of compressible soils at the site were taken from 2-1/2 inch diameter cased bore holes. The undisturbed samples were taken in 2 inch Shelby tubes using a piston type sampling apparatus and tested by standard procedures. The 2 inch diameter of the samples is generally considered too small for reliable sampling and testing.

Classification tests were performed and the range of results are shown in Table 1.

Unit dry weights in pounds per cubic foot of material placed at Camden are: Sand blanket, 110; embankment, 124; slag, assumed 100. At Point Pleasant they are: hydraulic fill, 114; sand blanket, 110; embankment, 120.

Consolidation tests were performed and pressure-void ratio and time-compression relationships were obtained. These relationships are shown graphically in Figs. 4 to 8, inclusive. Graphical determinations of the preconsolidation load (Ref. 1, pp 102-103) for individual samples showed the

TABLE I.

RANGE OF SOIL PROPERTIES

	Point Pleasant Project		Camden Project
	Gray Clay	Black Clay	Gray Clay
Depth (Feet)	10 - 26	26 - 41	10 - 53
Percentage Passing 0.05 mm	72 - 100	80 - 100	76 - 87
0.005 mm	30 - 50	39 - 68	16 - 31
Natural Water Content (% Dry Weight)	60 - 91	117 - 144	56 - 78
Natural Wet Density (#/Cu. Ft.)	95 - 107	82 - 92	87 - 102
Liquid Limit	97 - 106	134 - 163	38 - 92
Plastic Limit	41 - 54	80 - 85	29 - 55
% Loss on Ignition	—	24	7 - 10
Specific Gravity	2.65 - 2.70	2.60 - 2.67	2.50 - 2.62
Ultimate Unconfined Compressive Strength (Tons/Sq. Ft.)	0.45	0.18	0.37 - 0.50
Sensitivity (S') (Ref. 1, p. 160)	—	—	1.5 - 2.4

existing overburden load and the preconsolidation load to be approximately of the same magnitude. Therefore, the soils were considered to be normally consolidated. The presence of the slag layer at Camden indicates that the clay soils might be underconsolidated. Information obtained locally shows that the foundry from which the slag came was abandoned in 1912. The time elapsed is thus sufficient for nearly full consolidation of the clay under the weight of the slag layer.

Values of the vertical coefficient of consolidation (c_v) were obtained for individual consolidation test loadings where the time compression curves were adaptable to the method (Ref. 1, pp. 111-115) used. Figs. 6 and 8 show examples of time compression curves and Fig. 8 illustrates the method of determining c_v. Values of c_v vs. applied loads are plotted in Figs. 4, 5 and 7 and show a wide scattering of values. The value of c_v used to compute rates of settlement is the average value at a pressure equal to the pressure at the midpoint of compressible layer due to overburden pressure plus embankment pressure after removal of embankment overload.

Settlement Observations

The observed settlements were obtained by level readings on settlement platform pipes brought up through the embankment as work progressed. At the Point Pleasant Project, the pipes were left in place to obtain readings after paving. At Camden, readings after paving were taken on pavement and concrete curbs. Observed settlements vs. time are shown in Figs. 9 and 10.

At both projects, embankment settlement is considered mainly due to consolidation of the clay soils. Stakes upon which readings of both upward and horizontal movements could be taken by instrument were placed in rows outside the toes of slope at both projects. At Camden, the maximum horizontal movement of any stake was 0.56 ft., while the maximum upward movement was 0.16 ft. At Point Pleasant, the maximum horizontal movement was 0.84 ft. and the maximum upward movement was 0.79 ft. These maximum readings occurred in the areas where settlements are reported in this paper. They are isolated cases and not the rule. Some portion of the measured settlement should probably be attributed to plastic flow as deformations did occur outside the embankment. This portion would be small compared to the total settlement. No visible evidence of embankment rupture such as shear cracks was ever observed.

Additional evidence that the consolidation process occurred can be obtained from water contents of samples obtained at the Point Pleasant Project in December 1952 from beneath the embankment as compared to original water content values. Three separate borings were made through the embankment in the vicinity of Station 360+00. A sample of gray clay obtained from each boring showed water contents of 35, 41 and 56 for an average of 44 percent. At Station 360+00 prior to any construction, six samples of gray clay from one boring showed water contents of 56, 51, 58, 65, 92 and 87 for an average of 68 percent. This data is meager and the boring locations do not exactly coincide, but it is indicative that consolidation by expulsion of water did occur.

Estimated Settlements

Pressures on the compressible soils due to embankment loads were computed by use of the Newmark (Ref. 2) charts, assuming the embankments to be rectangular in shape instead of trapezoidal. Pressure-void ratio

relationships were obtained from the consolidation test results shown in Figs. 4, 5 and 7.

The total settlement at the center of embankment was then computed by means of the following formula:

$$S = \frac{e_1 - e_2}{1 + e_1} H \qquad (1)$$

Where S = Total Settlement

e_1 = void ratio at mid-point of compressible layer corresponding to pressure due to original overburden.

e_2 = void ratio at mid-point of compressible layer corresponding to pressure due to original overburden plus embankment.

H = total thickness of compressible layer.

The pressure-void ratio curves vary with individual samples. As the samples give a fair representation of the total depth, average curves shown in Figs. 4, 5 and 7 were used in estimating settlements.

The thickness of embankment used to obtain embankment pressure for computing total expected settlement was the distance from original ground to pavement profile plus the amount of settlement prior to paving. The process of obtaining the value of total settlement expected is one of trial and error. A settlement value is assumed so that total embankment pressure can be obtained to compute total settlement. The embankment weights must be corrected for buoyancy for portions that subside below water level. The computed settlement must agree with assumed settlement for the final trial.

Estimated Time Rate of Settlement

The methods used to estimate time rates of settlement are outlined herein and a sample calculation given in Appendix A. The method of estimating rate of embankment settlement where vertical sand drains have been installed is not readily available in the literature for complete solutions. Therefore, the method of solution used is presented together with assumptions made so that the validity of the estimated settlements will not have to be accepted without knowledge of how they were obtained.

The settlement of embankments is due to consolidation of the underlying soils. The consolidation process consists of expulsion of pore water from the underlying soil by application of pressure due to the embankment weight. The rate of expulsion of water depends on the nature of the soil, loading conditions and boundary drainage conditions.

As used herein, the terms percentage of consolidation and percentage of settlement are synonymous. The former refers to a decrease in the thickness of the compressible soil layer and the latter refers to the corresponding downward movement of the surface of the soil layer and the embankment placed upon it.

The percentage of consolidation ($\% U_v$) due to movement of pore water in a vertical direction only is given by Terzaghi (Ref. 3, Chap. XIII) as:

$$\% U_v = \text{function of } T_v \qquad (2)$$

$$\text{and} \quad T_v = \frac{c_v t}{H^2} \qquad (3)$$

Where T_v = a dimensionless number called the time factor (vertical flow).

c_v = coefficient of consolidation for vertical drainage.

t = time.

H = half thickness of compressible soil layer with drainage at top and bottom of layer.

The complex relationships of % U_v and T_v have been solved for various conditions of loading and drainage. For both projects, the pressures due to embankment are assumed uniform with depth and drainage possible at both top and bottom of the compressible layer. For these conditions, relationships of % U_v and T_v are available in soil mechanics literature (Ref. 1, p. 113).

Knowing the thickness of compressible layers and taking c_v (Figs. 4, 5 and 7) from laboratory data, values of T_v were computed by equation 3 for various values of elapsed time (t) and the corresponding value of % U_v obtained. % U_v when multiplied by the total expected settlement (S), computed by Equation 1, will give the magnitude of settlement due to vertical drainage up to various elapsed time.

For the Point Pleasant Project, where two compressible layers existed, it was assumed that the two layers were one with a value of c_v equal to the average c_v value for the two layers.

Without the installation of sand drains, rates of settlement would be computed as above for all pore water drainage would be vertical. However, with sand drains, pore water can drain horizontally in radial paths toward the sand drains.

For radial drainage only, the percentage of consolidation (% U_r) is given as:

$$\% U_r = \text{function of } T_r \quad (4)$$

and $$T_r = \frac{c_r t}{d_e^2} \quad (5)$$

and T_r depends on the value of a parameter (n)

and $$n = \frac{d_e}{d_w} \quad (6)$$

Where T_v = dimensionless number called the time factor (radial flow).

c_r = coefficient of consolidation for radial drainage.

t = time.

d_e = effective diameter of soil cylinder within which water will flow to sand drain.

d_w = diameter of sand drain.

The relationships of % U_r and T_r for conditons of radial drainage to sand drains for various values of n are given graphically by Barron (Ref. 4).

For both projects, the sand drains were installed on a square pattern. The effective diameter (d_e) was assumed as the diameter of a circle of area equal to the area of a square with sides equal to the distance between centers of sand drains.

For the Point Pleasant Project, d_e = 108", d_w = 20" and n = 5.4; for Camden, d_e = 135.5", d_w = 18", and n = 7.5 were the values used.

Values of the coefficient of consolidation for radial drainage (c_r) were not available. It is known that for stratified deposits the permeability is greater in the horizontal than vertical direction. As the coefficient of consolidation is directly proportional to permeability, it is therefore also greater horizontally (radially) than vertically. Various multiples of c_v were assumed as values of c_r and used to estimate the rates of settlement.

Assuming c_r and knowing d_e, values of T_r were computed by Equation 5 for various values of elapsed time (t). Having T_r the corresponding percentages of consolidation (% U_r) due to radial flow were obtained from curves presented by Barron.

Where vertical sand drains are installed, pore water drainage is both vertical and horizontal and both occur at the same time. Having determined for any time (t) the percentage of consolidation for each, they were combined by the following formula (Ref. 3, p. 291):

$$100 - \% U = (100 - \% U_v) \quad (100 - \% U_r) \quad (1/100) \qquad (7)$$

Where % U = combined percent consolidation.

% U_v = percent consolidation due to vertical drainage.

% U_r = percent consolidation due to radial drainage.

Having determined % U for various elapsed times, the estimated settlement up to that time was found by multiplying % U by the total estimated settlement.

In estimating rates of settlement, the embankment loads were subdivided into load increments. It was assumed that each load increment contributed a share of the settlement and that the settlement due to any one load increment proceeded independent of all other load increments. The share of settlement contributed by each loading was taken as equal to P_1/P, P_2/P, . . . where P_1, P_2 . . . are pressures due to weight of the load increments and P is the pressure due to the entire embankment weight after removal of overload above pavement profile elevation. The number of load increments into which the total embankment is divided depends on the accuracy of the settlement rates desired. As the estimated rate of settlement is only an approximate solution, the embankments were subdivided into load increments only where major changes of material or rate of placement occurred. The last load increment was taken as equal to the weight of material removed from above the pavement profile grade. The share this load increment contributed to settlement stops at time of overload removal.

As settlement is continually taking place during embankment construction, the pressure computed due to each load increment took into account the estimated settlement. As an example, if for an increment of load from Elevation + 10 to + 20 (10 ft.) the estimated settlement was one foot, the unit pressure due to the load increment would be 11 ft. times the unit weight of embankment material. However, to estimate the settlement during the time of filling, the load must be known. The process must therefore be one of trial and error. Pressures due to each load increment must be adjusted to account for an assumed settlement. Then the settlement must be computed for the increment to see if it agrees with the assumed value. This trial and error method need not be carried to any great refinement for small variations in pressures due to load increments does not greatly affect the overall estimated rate of settlement.

Each load increment was placed over a period of time. For computing the

rates of settlement, it was assumed that the entire increment was placed instantaneously at a time equal to the midpoint of the time taken to place the entire increment.

To summarize the method used to estimate rates of settlement, a sample calculation of computing expected settlement at the Camden Project is given in Appendix A.

Estimated settlements vs. time for various assumed values of c_r are shown together with the observed settlement for both projects in Figs. 9 and 10.

Discussion

The question of the effects of the so-called secondary consolidation upon embankment settlement has become the subject of considerable discussion in connection with sand drain projects. The laboratory time curves of both projects showed a portion of the 24-hour settlement to be due to secondary consolidation. In Figs. 4, 5 and 7 that portion of laboratory settlement occurring after the time of theoretical 100% consolidation (labeled U = 100%) is considered secondary consolidation. The observed settlements to date at each project continue after the time estimated for complete primary consolidation. No slope overload was placed on either project and some surface overload was used to adjust side slopes at time of paving. In the computations it was assumed that the pressure due to overload was entirely removed from all points beneath the centerline of embankment at the time of overload removal. In view of the width of the embankments, this assumption appears justified, but the placing of material on the slopes may have contributed to the settlement after overload removal.

Since paving at Point Pleasant, the observed settlement has been constant at about 0.1 ft. per year for 3 years. At Camden it has been about 0.16 ft. per year for 2 years. If these rates of settlement continue, the flexible pavement will ultimately require repaving.

Costs of such repaving should be taken into account when comparing alternate methods of stabilization for a project. Minor settlements after paving do not in any way indicate failure of a properly designed and constructed sand drain project.

In Figs. 9 and 10 it can be seen that for both projects the observed settlement parallels estimated settlements until the time when the embankment is completed. From then on, the observed settlements are at a much slower rate and tend to cross over the estimated values. For the Camden Project this can be better seen in Fig. 11 which shows estimated settlement based on observed total settlement to date, thereby reducing the error in calculated total settlement. Assuming the estimated values to be approximately correct for primary consolidation, it is apparent that some factor, be it secondary consolidation or not, enters the picture to cause the slower rates of settlement. If for these two specific projects the time of overload removal and paving had been established by the estimated time curves presented herein instead of by studies of actual rates of settlement, much larger magnitude of embankment settlement would have occurred after paving. The value of the field observations is readily apparent.

The laboratory results showed large variations in c_v for different samples and for loading increments of individual samples. This can be due to soil variations, disturbances in sampling, etc. No values of c_r or ratio of c_r to c_v were available and to measure them presents considerable difficulty. Samples of sufficient size can be trimmed and consolidation tests performed

with the horizontal layers in a vertical direction. Hirashima (Ref. 5) reports success in making field permeability tests to estimate the ratio of horizontal to vertical permeability and hence the ratio of c_r to c_v. Careful visual inspection of samples for stratification will assist in making an assumption of the ratio of c_r to c_v. As the establishment of the vertical sand drain spacing depends on c_r and c_v, an effort must be made during design to establish them as accurately as possible. After embankment construction is in progress and observations of settlement are made, the ratio of c_r to the laboratory value of c_v can be better established and any further computed predictions of settlement should be based on this value. In view of the difficulty in obtaining true values upon which to predict settlement, it is apparent that a fixed and unchangeable schedule of construction should not be set up in advance. Instead the schedule should be flexible so that timing can be adjusted in the field in order to obtain maximum settlement prior to paving.

CONCLUSIONS

It was not the purpose of this paper to arrive at any definite conclusions regarding settlement behavior at sand drain projects. However, the following are indicated:

1. Reasonable forecasts of the magnitude of settlement can be made.

2. Design factors, such as drain spacing, that control rate of settlement can be established within reasonable limits by practical application of the theory of consolidation.

3. As the true values of c_v and c_r are difficult to obtain and are not constant as assumed, as secondary consolidation appears to occur, and as other uncertainties are involved; the estimates of settlement rate are subject to error. Therefore, final decisions regarding amount of overload and time it should remain in place to achieve desired settlement appear to be a field decision based upon the rate of observed settlement.

4. Sand drains greatly accelerate the rate of settlement. Without them, the estimated settlement at time of overload removal would be only 28% completed at Camden and 33% completed at Point Pleasant. The estimated time for 95% settlement without sand drains is 33 years at Camden and 19 years at Point Pleasant. With sand drains, nearly complete settlement was achieved in about a two year construction period.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the many individuals of the New Jersey Highway Department and O. J. Porter & Co., Consulting Engineers, who were concerned with design and construction of the projects; to Professor Gregory P. Tschebotarioff, Princeton University, for encouraging the writing of this paper and making many helpful suggestions during its preparation; and to Mr. K. M. Rosser for preparing all illustrations and reviewing the manuscript.

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APPENDIX "A"

Camden Project
Estimated total settlement = 5.2 ft.
$c_v = 0.05\ ft^2/\ day$
Assume $c_r = c_v$
Embankment subdivided into four load increments with pressure due to each increment being:

$P_1 = 1.14$ tons/sq. ft.

$P_2 = 0.68$ " " "

$P_3 = 0.18$ " " "

$P_4 = 0.22$ " " "

P_4 = overload removal increment. Overload removed at 554 days.
Embankment started at zero days. Sand drains in place at zero days.
Thickness of compressible layer = 43 ft. = 2H
18" sand drains placed 10 ft. on centers
$d_e = 11.3$ ft.
$n = 7.5$
Problem: What is estimated magnitude of settlement at 650 days?
P = final embankment pressure
$= P_1 + P_2 + P_3 = 2.0$ tons/sq. ft.
Shares of consolidation contributed by each pressure (load) increment are:

$$\text{For } P_1,\ \text{Share} = \frac{P_1}{P} = 57\%$$

$$P_2,\ \text{Share} = \frac{P_2}{P} = 34\%$$

$$P_3,\ \text{Share} = \frac{P_3}{P} = 9\%$$

$$P_4,\ \text{Share} = \frac{P_4}{P} = 11\%$$

Share of P_1, P_2 and P_3 = 100%

$$T_v = \frac{c_v\ t}{H^2} = 0.000108\ t$$

$$T_r = \frac{c_r\ t}{d_e^2} = 0.00039\ t$$

At time T = 650 days

Load increment	1	in	place	619	days
"	2	"	"	557	"
"	3	"	"	512	"
"	4	"	"	388	"

388 days = total time load increment 4 was in place.
With t = 619 days

$T_{v1} = 0.067$ $T_{r1} = 0.242$

With t = 557 days

$T_{v2} = 0.061$ $T_{r2} = 0.217$

With t = 512 days

$T_{v3} = 0.055$ $T_{r3} = 0.200$

With t = 388 days

$T_{v4} = 0.042$ $T_{r4} = 0.151$

$\% U_v$ for above values of T_v from Ref. 4, page 721, gives:

$\% U_{v1} = 29$

$\% U_{v2} = 28$

$\% U_{v3} = 26$

$\% U_{v4} = 23$

Multiplying $\% U_v$ for each load increment by increment share of total percentage consolidation and adding gives total $\% U_v$ for total embankment weight.

29 x 57 = 16.5%
28 x 34 = 9.5%
26 x 9 = 2.3%
23 x 11 = 2.5%
Total = 30.8%

Thus total percentage consolidation ($\% U_v$) due to vertical drainage equals 30.8% at time = 650 days.

$\% U_r$ for above values of T_r from Ref. 4, page 722 for n = 7.5 gives:

$\% U_{r\,1} = 77$

$\% U_{r\,2} = 73$

$\% U_{r\,3} = 70$

$\% U_{r\,4} = 60$

Multiplying $\% U_r$ for each load increment by increment share of total percentage consolidation and adding gives total $\% U_r$ for total embankment weight:

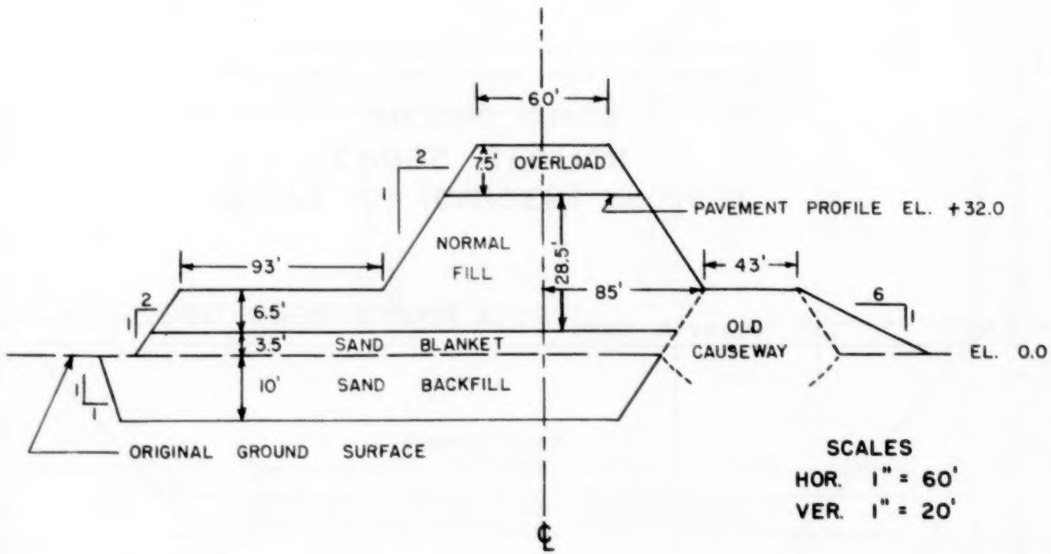
77 x 57 = 43.8%
73 x 34 = 24.8%
70 x 9 = 6.3%
60 x 11 = 6.6%
Total = 81.5%

Thus total percentage consolidation ($\% U_r$) due to radial drainage equals 81.5% at time = 650 days.

Total percentage consolidation (T U) due to both vertical and radial drainage at 650 days equals 87.2% from the formula:

$$100 = \% U = (100 - \% U_v) \ (100 = \% U_r) \ (1/100)$$

Estimated total settlement at 650 days = 87.2% x 5.2 ft. = 4.5 ft.

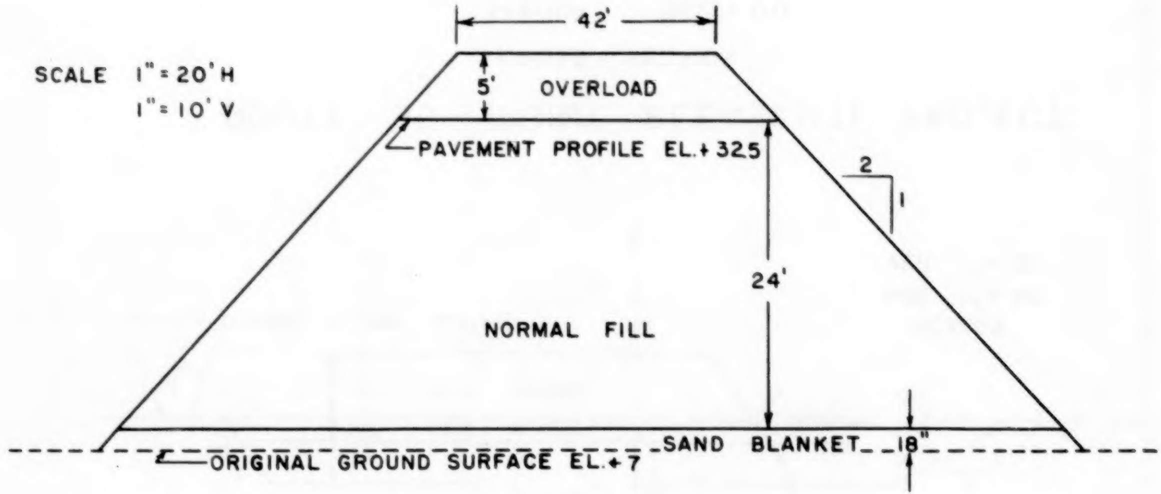


ROUTE 35 (POINT PLEASANT) PROJECT

CROSS SECTION

STATION 362 + 00

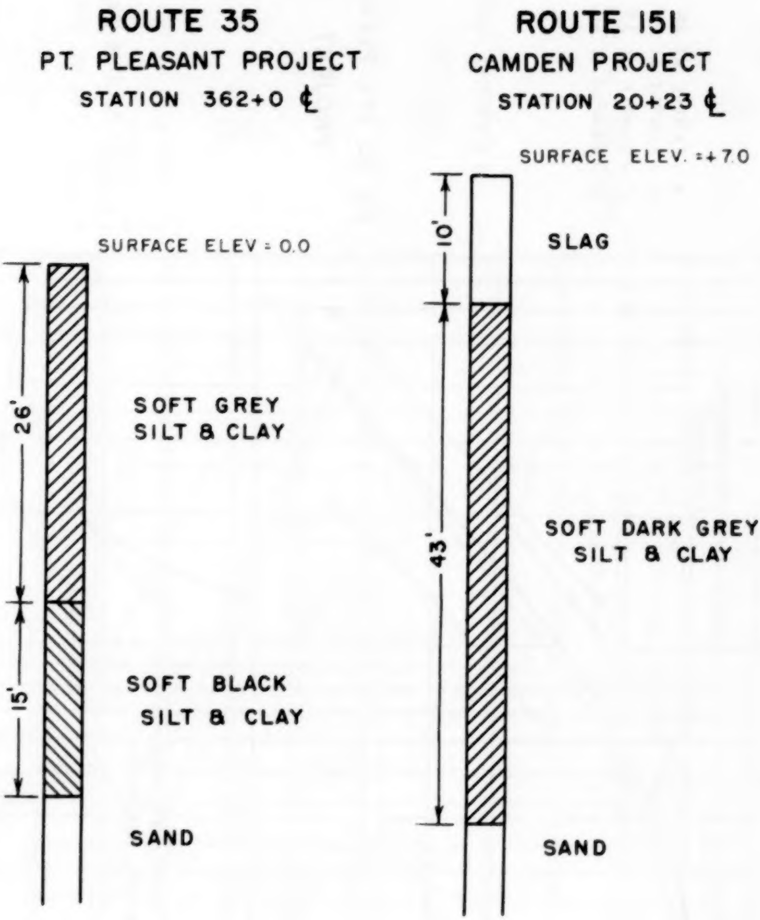
FIG. 1



ROUTE 151 (CAMDEN) PROJECT
CROSS SECTION
STATION 20+23

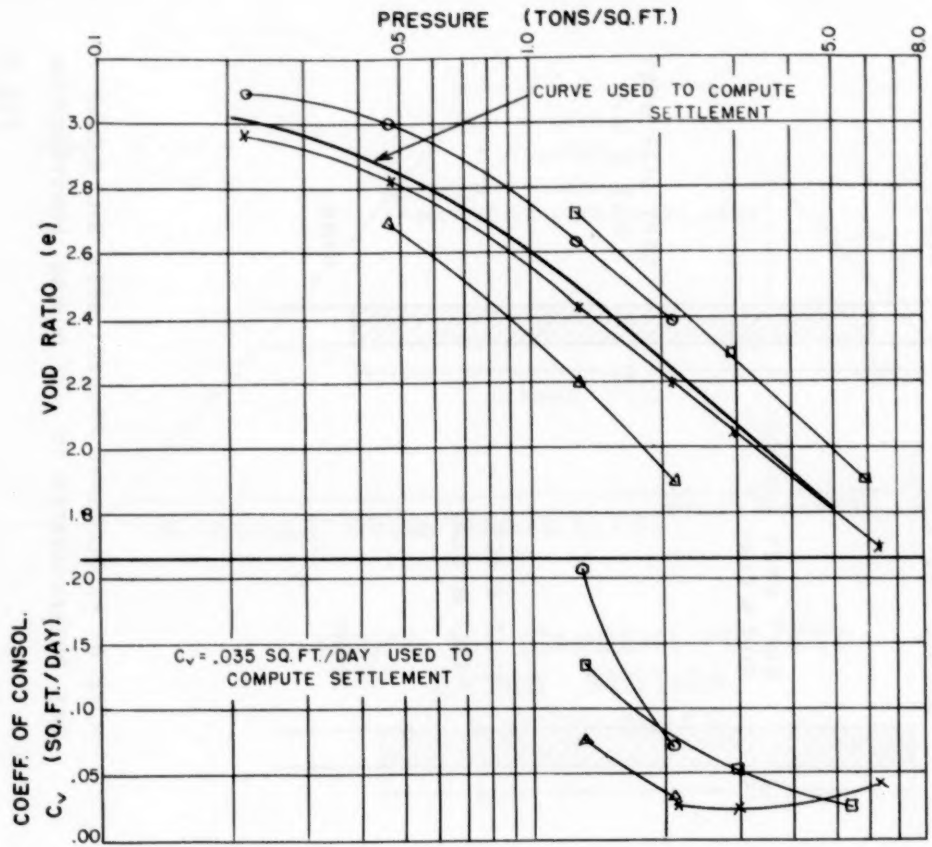
FIG. 2

SOIL PROFILES



NOTE: AT PT. PLEASANT PROJECT GREY SILT & CLAY WAS PRE-EXCAVATED TO -10' DURING CONSTRUCTION

FIG. 3

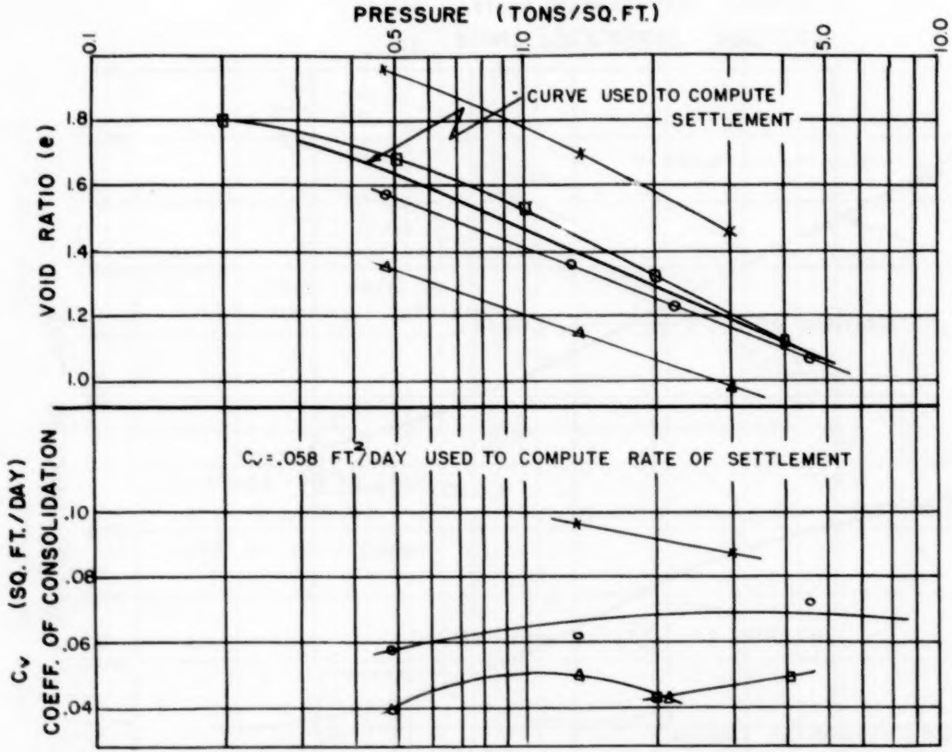


X = SAMPLE AT 26' DEPTH
Δ = SAMPLE AT 28' DEPTH
O = SAMPLE AT 33' DEPTH
□ = SAMPLE AT 36' DEPTH

RT. 35 (PT. PLEASANT) PROJECT

BLACK SILT & CLAY

FIG. 4



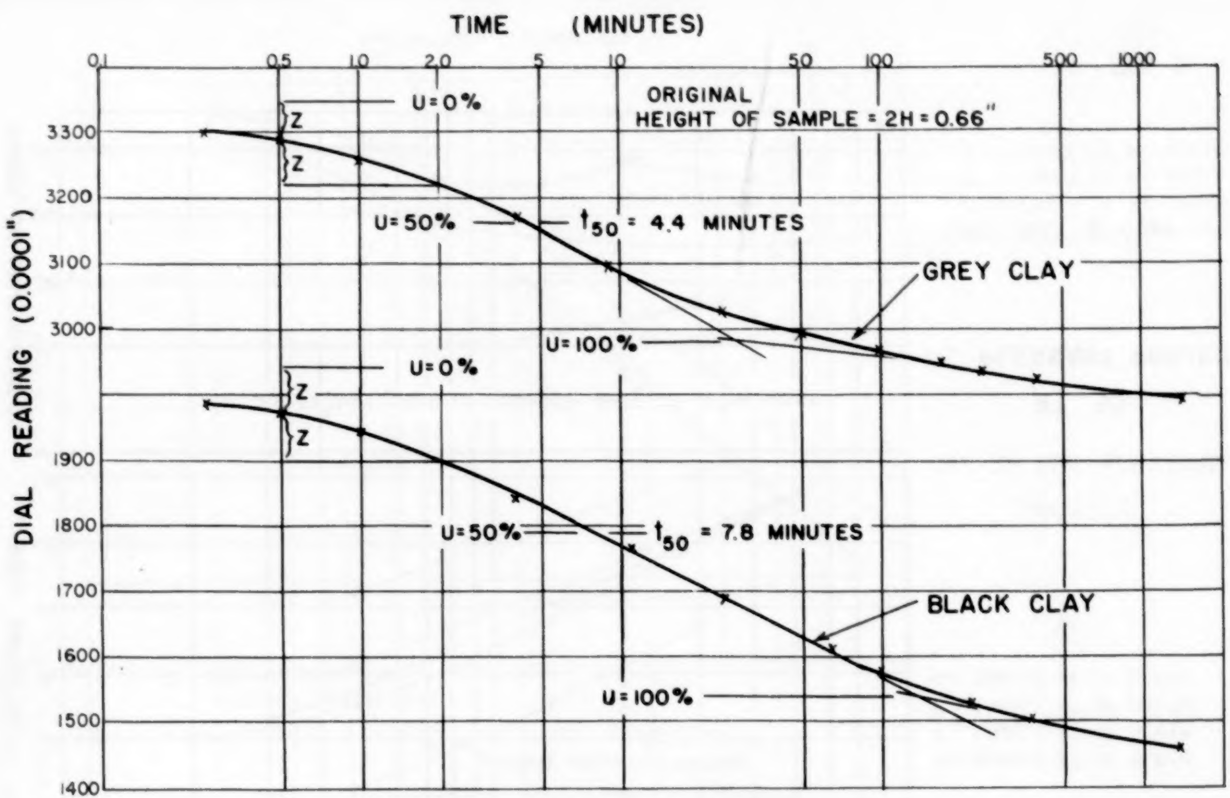
X = SAMPLE AT 10' DEPTH
▷ = SAMPLE AT 15' DEPTH
□ = SAMPLE AT 18' DEPTH
O = SAMPLE AT 21' DEPTH

RT. 35

PT. PLEASANT PROJECT

GREY SILT & CLAY

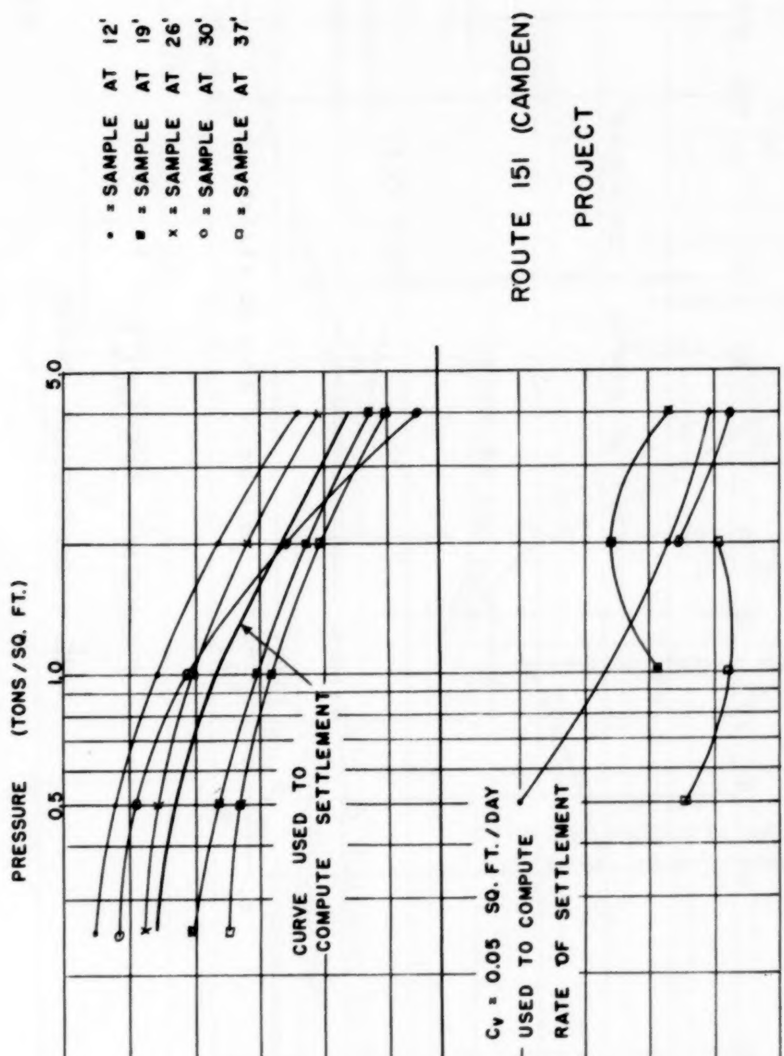
FIG. 5



POINT PLEASANT PROJECT

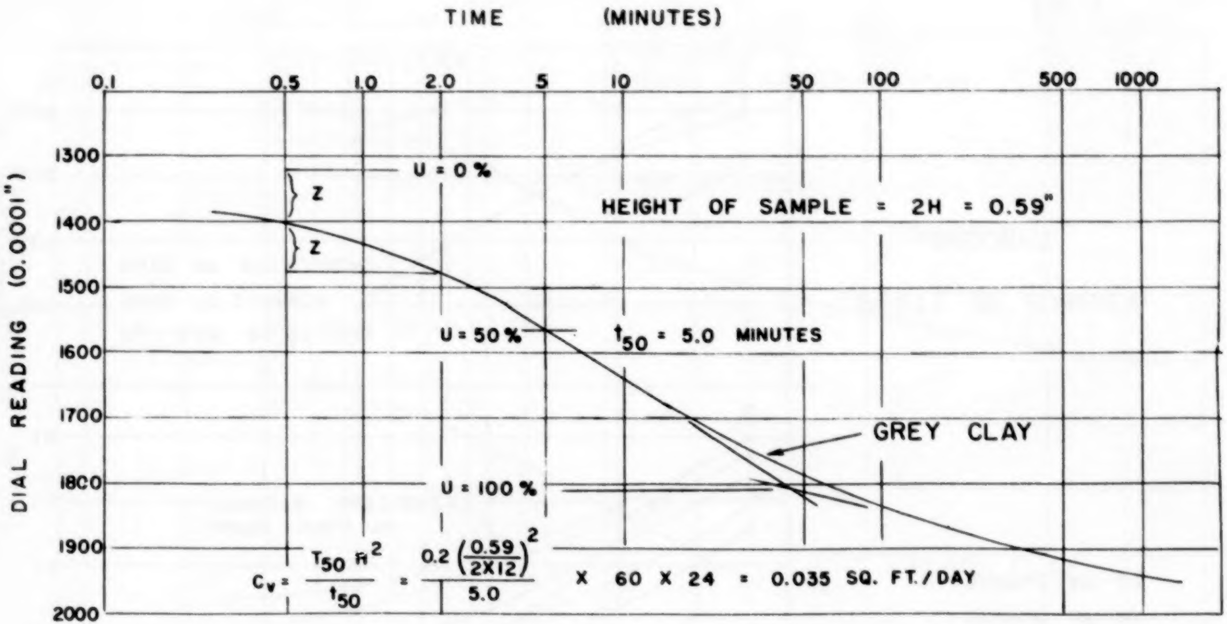
TIME — COMPRESSION CURVES

FIG. 6



PRESSURE (TONS / SQ. FT.)
0.1
0.5
1.0
5.0
VOID RATIO (e)
1.8
1.6
1.4
1.2
1.0
CURVE USED TO COMPUTE SETTLEMENT
COEFF. OF CONSOL. C_v (SQ. FT./DAY)
0.10
0.08
0.06
0.04
C_v = 0.05 SQ. FT./DAY USED TO COMPUTE RATE OF SETTLEMENT
• = SAMPLE AT 12'
■ = SAMPLE AT 19'
x = SAMPLE AT 26'
o = SAMPLE AT 30'
□ = SAMPLE AT 37'
ROUTE 151 (CAMDEN)
PROJECT

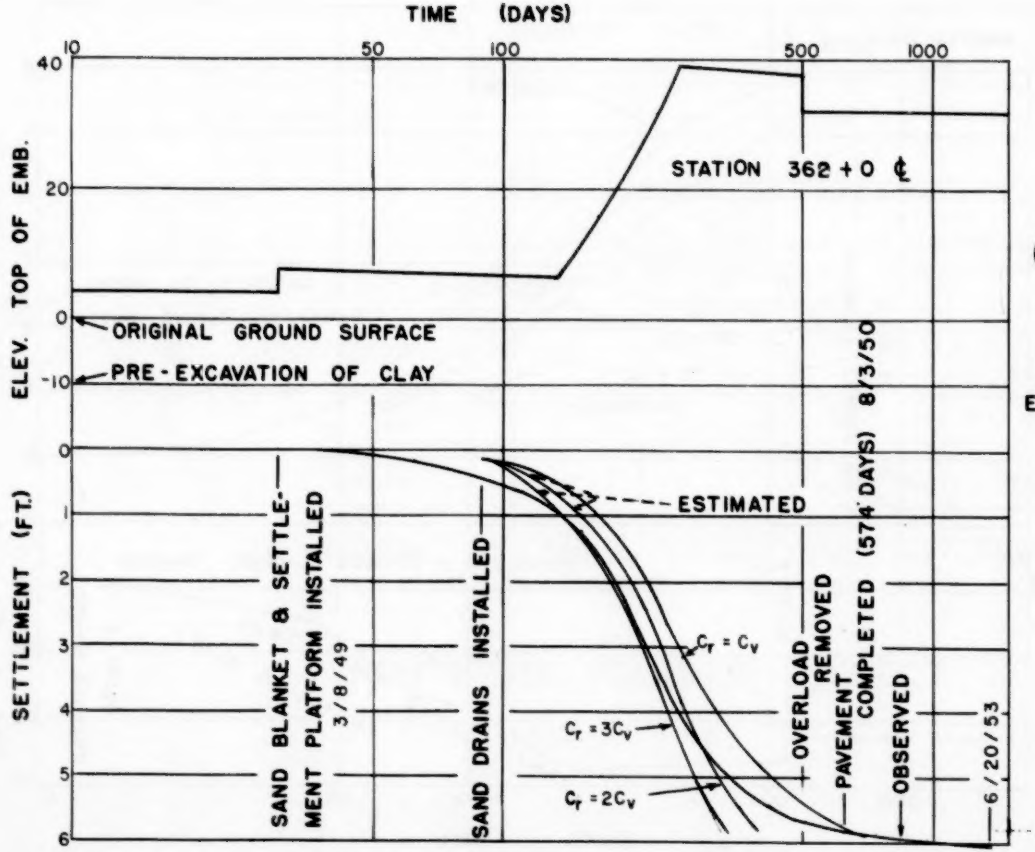
FIG. 7



CAMDEN PROJECT

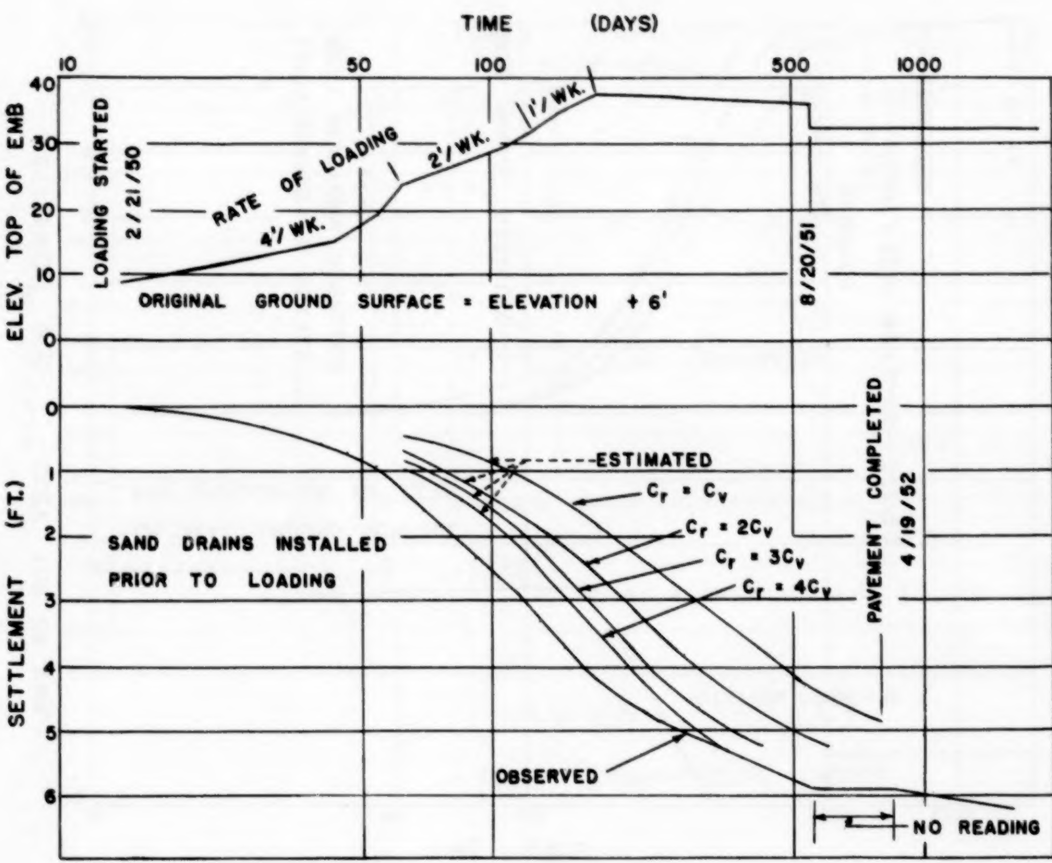
TIME - COMPRESSION CURVE

FIG. 8



ROUTE 35
(PT. PLEASANT)
PROJECT
SETTLEMENT & EMBANKMENT ELEV. VS. TIME

FIG. 9

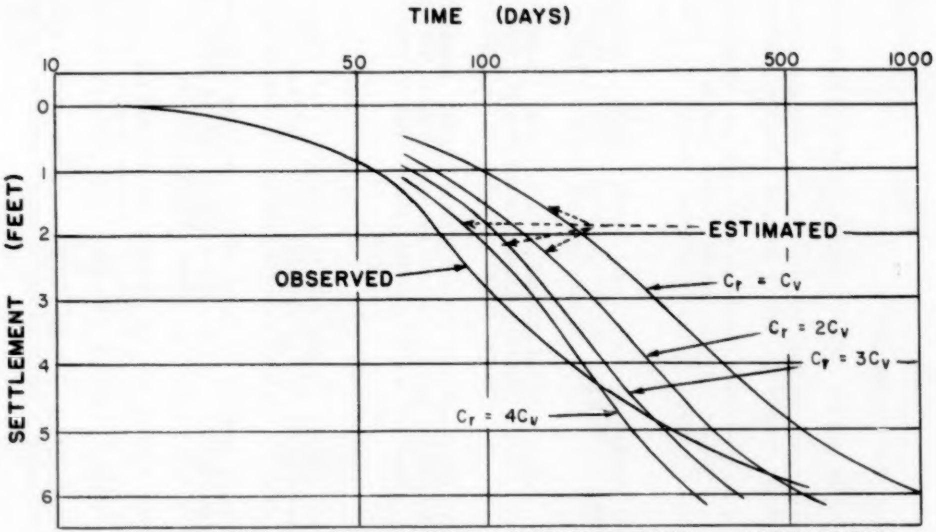


ROUTE 151
(CAMDEN PROJECT)

SETTLEMENT &
EMB. ELEV.
VS.
TIME

EST. SETT. = 5.2'

FIG. 10



ALL ESTIMATED SETTLEMENTS ASSUMED TOTAL SETTLEMENT EQUAL TO OBSERVED SETTLEMENT

ROUTE 151 (CAMDEN) PROJECT

SETTLEMENT VS. TIME

FIG. 11

PROCEEDINGS PAPERS

The technical papers published in the past year are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

VOLUME 80 (1954)

JULY: 457(AT), 458(AT), 459(AT)[c], 460(IR), 461(IR), 462(IR), 463(IR)[c], 464(PO), 465(PO)[c].

AUGUST: 466(HY), 467(HY), 468(ST), 469(ST), 470(ST), 471(SA), 472(SA), 473(SA), 474(SA), 475(SM), 476(SM), 477(SM), 478(SM)[c], 479(HY)[c], 480(ST)[c], 481(SA)[c], 482(HY), 483(HY).

SEPTEMBER: 484(ST), 485(ST), 486(ST), 487(CP)[c], 488(ST)[c], 489(HY), 490(HY), 491(HY)[c], 492(SA), 493(SA), 494(SA), 495(SA), 496(SA), 497(SA), 498(SA), 499(HW), 500(HW), 501(HW)[c], 502(WW), 503(WW), 504(WW)[c], 505(CO), 506(CO)[c], 507(CP), 508(CP), 509(CP), 510(CP), 511(CP).

OCTOBER: 512(SM), 513(SM), 514(SM), 515(SM), 516(SM), 517(PO), 518(SM)[c], 519(IR), 520(IR), 521(IR), 522(IR)[c], 523(AT)[c], 524(SU), 525(SU)[c], 526(EM), 527(EM), 528(EM), 529(EM), 530(EM)[c], 531(EM), 532(EM)[c], 533(PO).

NOVEMBER: 534(HY), 535(HY), 536(HY), 537(HY), 538(HY)[c], 539(ST), 540(ST), 541(ST), 542(ST), 543(ST), 544(ST), 545(SA), 546(SA), 547(SA), 548(SM), 549(SM), 550(SM), 551(SM), 552(SA), 553(SM)[c], 554(SA), 555(SA), 556(SA), 557(SA).

DECEMBER: 558(ST), 559(ST), 560(ST), 561(ST), 562(ST), 563(ST)[c], 564(HY), 565(HY), 566(HY), 567(HY), 568(HY)[c], 569(SM), 570(SM), 571(SM), 572(SM)[c], 573(SM)[c], 574(SU), 575(SU), 576(SU), 577(SU), 578(HY), 579(ST), 580(SU), 581(SU), 582(Index).

VOLUME 81 (1955)

JANUARY: 583(ST), 584(ST), 585(ST), 586(ST), 587(ST), 588(ST), 589(ST)[c], 590(SA), 591(SA), 592(SA), 593(SA), 594(SA), 595(SA)[c], 596(HW), 597(HW), 598(HW)[c], 599(CP), 600(CP), 601(CP), 602(CP), 603(CP), 604(EM), 605(EM), 606(EM)[c], 607(EM).

FEBRUARY: 608(WW), 609(WW), 610(WW), 611(WW), 612(WW), 613(WW), 614(WW), 615(WW), 616(WW), 617(IR), 618(IR), 619(IR), 620(IR), 621(IR)[c], 622(IR), 623(IR), 624(HY)[c], 625(HY), 626(HY), 627(HY), 628(HY), 629(HY), 630(HY), 631(HY), 632(CO), 633(CO).

MARCH: 634(PO), 635(PO), 636(PO), 637(PO), 638(PO), 639(PO), 640(PO), 641(PO)[c], 642(SA), 643(SA), 644(SA), 645(SA), 646(SA), 647(SA)[c], 648(ST), 649(ST), 650(ST), 651(ST), 652(ST), 653(ST), 654(ST)[c], 655(SA), 656(SM)[c], 657(SM)[c], 658(SM)[c].

APRIL: 659(ST), 660(ST), 661(ST)[c], 662(ST), 663(ST), 664(ST)[c], 665(HY)[c], 666(HY), 667(HY), 668(HY), 669(HY), 670(EM), 671(EM), 672(EM), 673(EM), 674(EM), 675(EM), 676(EM), 677(EM), 678(HY).

MAY: 679(ST), 680(ST), 681(ST), 682(ST)[c], 683(ST), 684(ST), 685(SA), 686(SA), 687(SA), 688(SA), 689(SA)[c], 690(EM), 691(EM), 692(EM), 693(EM), 694(EM), 695(EM), 696(PO), 697(PO), 698(SA), 699(PO)[c], 700(PO), 701(ST)[c].

JUNE: 702(HW), 703(HW), 704(HW)[c], 705(IR), 706(IR), 707(IR), 708(IR), 709(HY)[c], 710(CP), 711(CP), 712(CP), 713(CP)[c], 714(HY), 715(HY), 716(HY), 717(HY), 718(SM)[c], 719(HY)[c], 720(AT), 721(AT), 722(SU), 723(WW), 724(WW), 725(WW), 726(WW)[c], 727(WW), 728(IR), 729(IR), 730(SU)[c], 731(SU).

JULY: 732(ST), 733(ST), 734(ST), 735(ST), 736(ST), 737(PO), 738(PO), 739(PO), 740(PO), 741(PO), 742(PO), 743(HY), 744(HY), 745(HY), 746(HY), 747(HY), 748(HY)[c], 749(SA), 750(SA), 751(SA), 752(SA)[c], 753(SM), 754(SM), 755(SM), 756(SM), 757(SM), 758(CO)[c], 759(SM)[c], 760(WW)[c].

c. Discussion of several papers, grouped by Divisions.

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